Analysis of the RED Aerosol Data Set by the NRL Aerosol Model Driven by COAMPS

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LONG-TERM GOALS

Identify, understand and quantify all the physical processes that govern the aerosols in the marine environment and develop a mechanistic model that predicts the evolution of the aerosol size and composition distribution. From such a model aerosol extinction of EM radiation can be calculated in a highly structured atmospheric marine boundary layer (AMBL) and used to evaluate and predict the performance of systems that operate at visible and infrared wavelengths.

OBJECTIVES

The objectives of the current work are (1) to develop an interface that allows the NRL aerosol model to assimilate the required meteorological data from the output of a meteorology model. This provides data necessary to calculate an air mass trajectory along which the aerosol model can travel to any geographical point in the domain and will supply the many meteorological inputs required by the aerosol model. (2) To use this integrated modeling approach together with the RED (rough evaporation duct experiment) data set as a diagnostic tool to derive an improved sea-salt aerosol source function. And (3) add to the aerosol model the capability to include large-scale vertical air motions (subsidence/lifting) given by the meteorological model. This is a major task because each size section moves with a different vertical velocity given by the sum of the gravitational settling velocity and the vertical air velocity, and because changes in vertical air velocity require horizontal divergence that also changes the aerosol concentration in a vertical cell. In prior versions of the aerosol model the only vertical exchanges were those resulting from gravitational settling and turbulent mixing.

APPROACH

To calculate/predict EM extinction (at any wavelength) resulting from aerosols in a highly structured AMBL, the evolution of the aerosol size and composition distributions are required. Many of the aerosol source, sink and transformation processes are highly dependent on meteorological parameters such as wind speed, humidity profile, clouds, precipitation scavenging, etc. The NRL 1-D aerosol-

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processes model includes all these processes but needs real meteorological data as input to calculate the evolution of the size distribution. The aerosol model is typically run with 37 size sections (between 0.005 and 15 μm dry radius) and four components, sulfate, sea salt, an insoluble component (dust), and water in equilibrium with the soluble components at ambient RH. To fully integrate an aerosol model into a 3-D meteorological model would require carrying and calculating over 100 aerosol variables at each grid point of the model in addition to the meteorological variables. Rather than fully integrating the aerosol model into the meteorological model the following strategy is being pursued: A high-resolution mesoscale model, in our case the Navy's COAMPS model, is run over the geographical region and time of interest and the meteorological variables at each grid point are stored at specified time intervals, typically every hour. An important feature of COAMPS is the nested grid feature. After running COAMPS over a large area the output is used to initialize a nested grid, giving higher resolution the area of interest. Also having the aerosol model independent of the meteorological model makes it possible to run the aerosol model at higher vertical resolution than is possible with COAMPS, whose vertical resolution is fixed regardless of the horizontal grid resolution. In addition to the normal meteorological fields, some internally generated parameters such as the turbulent mixing coefficients generated by the boundary layer parameterization used in the model are also saved. From the horizontal wind field, a mean AMBL back trajectory from any point of interest is generated. The NRL 1-D aerosol model, here considered as a vertical column, is advected along this trajectory. The metrological data required by the aerosol model is extrapolated using the grid points that lie closest to the points on the back-trajectory. Because of the well-mixed character of the AMBL, the concept of a 1-D column moving with the mean wind speed in the AMBL is a reasonable approximation. The height of the AMBL is determined in the model by the profile of exchange coefficients, which extends into the free troposphere.

WORK COMPLETED

(1) In the original aerosol model (Fitzgerald et al., 1998a, 1998b; Gelbard et al., 1998), large-scale vertical motions were not included. Locally, the effects of turbulent mixing in the AMBL are much stronger than large-scale divergence that can often be neglected over short time periods. An analytical study of the effect of vertical motions led to the conclusion that typical large scale vertical motions (subsidence/lifting) can be very important on time scales longer than several hours and suggests, for that reason, some of the prior work on determination of the sea-salt source function is of questionable value (Hoppel et al, 2002). We have how developed a version of the aerosol model that allows a vertical velocity variation with height (this is provided by COAMPS). This has proven to be more difficult than originally anticipated, largely because the amount of mass added or subtracted to a vertical cell (due to horizontal convergence/divergence) must exactly balance the difference in that which flows through the upper and lower cell boundaries for each size section in the case when there is no vertical gradient in mass densities in the sections. Any imbalance gives a spurious source/sink of particles that can causes a large excess/deficit of aerosol mass with time. Of course, if there is any gradient in the mass density, that gradient must be moved up/down depending on the vertical velocity. Furthermore gravitational settling of larger particles will often exceed the upward motion of the air so that aerosol particles do not follow the air motion. All these issues are addressed in the new version of the model that is undergoing final testing.

(2) COAMPS has been modified to output all meteorological parameters required to drive the aerosol model. COAMPS has been rerun with three stages of nesting in the region of the RED (Rough Evaporation Duct) experiment for the entire time period and the data archived.

(3) A back trajectory analysis program was secured form NOAA, modified to work on the COAMPS output data and the results made available to all RED investigators. Furthermore a program that extracts and interpolates the data required to run the aerosol model along the back trajectory has been written and tested.

RESULTS

In addition to the results given above, we cite the following significant advances.

1. The research on the effects of vertical velocity and deposition velocity revealed that the dry deposition velocity for a uniform surface source of particles, such as sea-salt aerosol, is fundamentally different than that of a source of particles from above or upwind. This has far reaching implications since all numerical models use the same deposition velocity for sea-salt over the ocean as for aerosols supplied from above. Application of the deposition velocity for a uniform surface source results in a corrected Smith et al. (1993) sea-salt source function. The equilibrium method of deriving the sea-salt source function from an aerosol concentration measured at a reference height and the deposition velocity is shown to be of little value for particles smaller than about 5 to 10 μm in radius for two reasons: (i) the time to establish equilibrium between the source and loss by dry deposition is much longer than the typical lifetime of small particles determined by precipitation scavenging and (ii) it is difficult if not impossible to remove the effect of synoptic-scale vertical velocities and the effect of mixing between the marine boundary layer and the free troposphere. A sea-salt aerosol source function that combines the Monahan et al. (1986) formulation at radii smaller than about 10 μm with the corrected Smith et al. (1993) formulation at radii larger than 10 μm has been published (Hoppel et al., 2002)

2. We have developed a 1-D model that allows for a vertical velocity profile to be incorporated. The program will automatically provide the source or sink of particles to a vertical layer as required by the vertical velocity gradient derived from the COAMPS data.

IMPACT/APPLICATIONS

Aerosols scatter and absorb EM radiation and are a primary source of extinction in the visible and IR portions of the EM spectrum. To calculate aerosol extinction as a function of wavelength requires knowledge of the aerosol size distribution along the optical path. Hence aerosols are important to: (i) DoD systems which use visible or IR wavelengths, such as EO (electro-optical) systems for surveillance, guidance and control, (ii) remote sensing in the visible and IR where aerosol corrections are often important (example: sea-surface temperature), and (iii) radiative transfer calculations required in global and climate models.

Long-term impact. While detailed microphysical aerosol models which can predict the aerosol size distribution are in their infancy, rapid progress is being made in understanding the important physical and chemical aerosol processes and integrating these processes into a comprehensive aerosol/meteorological model. This work is making a substantial contribution toward the next generation of aerosol modeling.

Immediate impact. We have developed an interface between a microphysical aerosol model and a meteorological model that will provide the met data necessary to run the aerosol model under realistic conditions. While this model is not an operational model since the aerosol data necessary to initialize it is not routinely available, it is a valuable diagnostic tool to interpret data from field experiments that will improve our understanding of aerosol processes and aerosol sensitivity to meteorological conditions. The first application of this will be the model's use with the RED data set, hopefully to determine an improved sea-salt aerosol source function for use in aerosol models.

TRANSITIONS

We have shown that the aerosol deposition velocity currently used in all models is fundamentally incorrect for a surface source of aerosols, such as, sea-salt aerosol and have provided a deposition velocity formulation which can be used for sea-salt aerosol in future models. This new formulation can/should be used in all aerosol models for those particles, which have a local source at the earth's surface. This includes the more numerous, less sophisticated bulk aerosol models (which carry aerosol mass, but do not determine the size distribution).

RELATED PROJECTS

Much of the work reported here in conjunction with the RED (rough evaporation duct) experiment sponsored by ONR 322 and SPAWAR 155. We plan to use the data from the RED experiment together with our aerosol modeling effort to derive and improved sea-salt aerosol source function. (http://sunspot.spawar.navy.mil/2858/index.html)

Increased interest in aerosols generated by the climate change program, by remote sensing requirements, and by radiative transfer calculations in global models is driving the growing interest and research funding for aerosols. It would be impossible to list all these efforts here. However there is very little work being done developing detailed aerosol processes models in the Climate Change program. The primary difference is in the scale of interest. Local visibility and DoD applications require spatial resolution on the local and regional scale, while climate modeling requires global characterization. It is clear, however, that the small-scale processes drive the larger scale phenomena, and are necessary for any predictive model of climate change. For climate change prediction the national program recognizes a need for process-oriented studies (in addition to global aerosol data) for evaluating the effect of different policy scenarios.

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